Chapter 4
Data Evaluations and Troubleshooting in Well System Maintenance

Making and refining maintenance decisions and evaluating the degree of maintenance action success requires a systematic and effective data evaluation and troubleshooting process. Organizing such a process requires both institutional and technical planning.

4-1. Institutional and Funding Issues in Maintenance Planning, Analysis and Execution

a. Historic lack of well O&M planning. Successful O&M of any mechanical system such as a pumping well array requires an institutional structure and indoctrination that preventive maintenance is valuable and indeed essential in preventing future problems. This is well demonstrated for wells in a variety of operating settings (including water supply, dewatering, and hydraulic relief) and particularly well demonstrated in HTRW remediation. Despite the well-known vulnerability of monitoring and remediation wells to performance degradation, provisions for preventive design and maintenance are routinely shortchanged in practice (e.g., Smith 1995; Alford and Cullimore 1999).

b. Institutional and contractual barriers to well O&M implementation. A persistent problem in encouraging rational well maintenance planning and execution is the array of roadblocks that discourage the implementation of these logical behaviors in the HTRW remediation field. In the project development-contract administration process, USACE internal professionals or a contracted architectural-engineering (AE) firm develops a scope of work (SOW), specifications, and design. Once a contract is let, the work is administered by Construction teams. It is imperative that well system O&M be explicitly incorporated into the SOW and specifications, and included as an issue in design (designing for ease of maintenance). Likewise, contract administration needs to enforce the well system O&M imperatives of the SOW.

(1) History and experience (e.g., Smith 1995; Alford and Cullimore 1999) demonstrate the necessity of planning and adequately funding well system O&M oversight and professional review. Such funding and O&M planning (with professional review):

- Should be an integral part of Title II HTRW remediation planning and funding activities at the outset of project development, and should be included in any specifications or SOWs involving the monitoring and pumping of ground water.
- Should be part of the USACE review checklist.
- Should include maintenance monitoring data management as an integral part of site data management.
- Should ensure that, once constructed and active, HTRW remediation projects have the funding budgeted and available to perform adequate routine well system maintenance monitoring, repair, replacement, and cleaning as part of the overall site and system O&M contract.
- Should be protected to the extent possible contractually from transfer to other purposes.

(2) Checklists for well system O&M maintenance planning are addressed in Chapter 8 and examples provided in Appendix D.

c. Expected outcomes of a lack of maintenance planning. The logical necessity of such planning takes the form of a typically remorseless "pay me now or pay me later" scenario:

(1) Filter and other water treatment clogging occur due to constituents pumped from wells that supply the treatment plants. Some of this is unavoidable, but others, such as biofouling buildup, can be minimized by preventive maintenance actions at the well source.

(2) Hydraulic losses due to clogging occur that can be prevented and mitigated in the same way by maintenance activities at the well source and preventive engineering design that reduces choke points and permits line service.

(3) Perhaps most costly of all is a situation where the project's objectives (ground water cleanup) are not achieved or delayed due to preventable well field problems.

d. The extent of O&M monitoring must be determined. Chapter 2 reviews testing recommended and minimum data elements needed to define conditions that could cause well system clogging and corrosion. Chapter 3 defines the historical background needed to establish trends. Once a baseline of information on site hydrogeology, biogeochemistry, and operations is established, and trends become apparent through scheduled monitoring (Chapter 5), the level of effort appropriate to detect deteriorating conditions can be established.

4-2. Quarterly Review of Site Performance Data

a. Schedule of performance review. At a minimum, projects should review performance and other maintenance monitoring data (Chapter 2) regularly. Doing so quarterly is a common recommendation and fits into typical project review schedules. At this time project's operational team reviews data and operational information to answer the questions: "Where do we stand now?" and "What do we expect to happen?"

b. Personnel versatility. A review of the range of information required for baseline well field maintenance monitoring (Chapter 2) shows that it is multidisciplinary. It is highly recommended that the project involve personnel experienced in well field maintenance information review and interpretation. Such persons (or a team of persons) should be conversant with all of the following sections. Desirable qualifications of personnel should be incorporated in bid specifications if O&M contractors are to be expected to comply with them.

4-3. Baseline and Historical Data for Wells/Site

a. Background. Chapters 2 and 3 outline necessary baseline and historical well and site information and how it should be managed to facilitate O&M planning. A crucial element is the availability of historical information and the means to interpret that information. If possible, information should be available extending back to site characterization studies and forward to the present to aid in evaluation of processes and activities affecting the maintenance of the well system. O&M personnel can predict trends based on data gathered during troubleshooting, but uncertainty is higher than with actual historical data.

b. Historical data management. An essential element in this process is a data management system that permits the detailed tabulation, plotting, cross-reference, and statistical analysis of a broad range of information as described in Section 2-10. A system that stores and permits the easy retrieval and cross-referencing of a variety of information without artificial topical boundaries helps human troubleshooters and planners to see patterns that may not be immediately obvious. This archive may be physical and the retrieval system a knowledgeable human, or on a computer. Project data systems should permit:

- Charting of information (e.g., pumping water levels) back to the site's characterization and development at flexible scales.
- Cross-referencing of various data to look for trends (e.g., specific capacity vs. lithology or biofouling indicators).
- Data access by (or to be maintained by) the department or firm responsible for O&M if these tasks are split from regulatory oversight.

c. *Human operational experience and its preservation and transfer*. As useful as data and other information are, they are most valuable when filtered through human operational experience. All systems have quirks or features that defy the kind of quantification possible in a computer database file.

(1) Filing systems are imperfect and incomplete. Human experience provides the kind of anecdotal background that is often most useful in troubleshooting. For example, noting that problems began when there was a change in pumps.

(2) HTRW remediation site maintenance planning should make provision for:

- Regular recording of maintenance actions and observations by operating personnel.
- Minimizing personnel changes to preserve memories.
- Ensuring that key operating personnel are well-informed and trained in their tasks.
- Outside expert assistance on an as-needed basis.

4-4. Operator/Working Crew Leader Qualifications and Training

Well-trained and motivated onsite operating personnel are crucial in successful O&M management. Frequent turnover, poor training, and lack of positive motivation will defeat even the most well-crafted O&M plan. While requirements may vary, the following are essential:

a. Institutional continuity and "ownership" of the O&M plan and its execution are crucial in fulfilling any plans to properly maintain well arrays. Experience shows that if maintenance is the personal crusade of one person, but not adopted by the entire site operator crew and management, that crusade ends if the original enthusiast leaves.

b. The operators on site must understand the O&M plan, the purpose of its activities, and why they are important to the operation of the remediation system. At a minimum, the operations supervisor should understand and be able to verify field data collection, manage and participate with field personnel in daily maintenance actions, and enforce common sense issues during daily operation.

c. For these reasons, training is essential. All personnel responsible for well array O&M should be formally trained in the O&M plan, its components that pertain to the well system, and essential tasks (Chapters 2 and 3).

4-5. Determination of Operational Maintenance Responsibilities

An important consideration in well system O&M is defining the roles of plant management and operational personnel in scheduling, analyzing, reviewing, and revising various O&M activities. These can be divided into two primary levels.

a. Plant manager -- project level. This person or team operates at the level of the HTRW remediation project's management level and integrates O&M activities into the overall project goals and structure. Primary tasks related to well system O&M:

- Sets up maintenance action schedules
- Follows up to ensure actions are accomplished
- Is responsible for data collection and evaluation
- Prepares status report of evaluations
- Seeks and works with outside expert help as needed.

b. Designated oversight personnel -- operations level. This person or group operates at the HTRW remediation site level. If a separate O&M Company oversees the regular function of the site's physical plant, then this group may consist of both the O&M company's management and onsite personnel. Their work scopes involve:

- Assisting in maintenance schedules and making recommendations for modifications based on site-level experience with individual wells.
- Conducting necessary training of pertinent personnel (as necessary with outside expert assistance).
- Being responsible for enforcing maintenance actions and reporting to the plant manager.

4-6. Biological Activity Implications

a. Biological activity importance to O&M. Section 2-9 reviews biological maintenance monitoring needs. However, HTRW remediation projects are typically designed by personnel (environmental engineers and hydrogeologists) who typically have a limited background in microbiology. It is important to understand the purposes for the emphasis on bioassay in maintenance monitoring for it to be properly implemented.

(1) Production and hydraulic efficiency loss. Historically, the primary factor in well system production loss on HTRW projects is biological activity (e.g., Leach et al. 1991; Smith 1995; Alford and Cullimore 1999; ASTM D 5978). Biofouling has been identified as a primary cause of well performance problems in "clean" water supply for many years (e.g., Borch, Smith, and Noble 1993; Cullimore 1993), For ground water contaminant plumes, unless the predominant contaminant is biologically recalcitrant (such as TCE, for example), microbial activity is greatly accelerated and increases the rate of biological corrosion and clogging.

(2) Effects of "representativeness" of monitoring samples. Biofilms, which serve protection and scavenging functions for microorganisms that form them, naturally have the effect of attaching and holding organic molecules and some metals. Consequently, it has been recognized that monitoring well samples may not always be representative of bulk-formation ground water quality (unpredictable accuracy). Smith (1995;1996) reviews the limited literature on this subject relevant to monitoring. This effect and its implications are recognized in ASTM D 5978.

(3) "Unexpected" geochemical changes. Biological activity has the tendency to induce or accelerate processes that may be unlikely or much slower in an abiotic environment. For example, biological corrosion occurs in environments considered "encrusting" in Langelier, Ryznar, or similar indices (Borch, Smith, and Noble 1993). Iron and occasionally manganese clogging accelerates where metal-precipitating bacteria flourish. Iron, manganese, and sulfur ($S^0$0 or SO_4^{2-}) reduction processes (all entirely microbial) mobilize large amounts of iron, manganese or sulfide (S^{2-}) into solution. The S^{2-}

readily combines with dissolved iron (Fe^{2+}) to form encrusting iron sulfide minerals. Iron oxidation is also driven anaerobically by denitrification. The CO_2 generated by microbial respiration drives carbonate equilibrium toward bicarbonate saturation. These and other microbial effects tend to complicate geochemical estimating.

b. The importance of biological assays in maintenance monitoring. These assays provide:

- An "early warning" method of predicting biological effects on geochemical transformations such as predicting ferrous sulfide mineral formation in a 12.9^{o} C (55^{o} F) alkaline carbonate ground water when SRB are detected.
- Means of evaluating changes in biological activity over time. In this, the historic record is essential.

c. Interpretation. At the present time, the interpretation of biological assay information is not always straightforward. Because the existing assay tools are inexact, proper interpretation is critical (but becoming easier). Because interpretation is somewhat subjective and changing over time (e.g., compare Smith 1992; Cullimore 1993; and Smith 1996), it is useful to involve personnel experienced with this type of testing in planning an O&M program and in forming the O&M management team (Section 4.5). The references to literature and web site resources provided (Appendix A) offer a background in the types of effects to expect.

4-7. Impacts on Plant

The scope of this document does not extend to treatment plant O&M; however, it has become evident that bio-physical-chemical activity in wells (pumping and injection) has a direct influence on plant and project mission performance. In addition to the routine effects of pumped water quality on the plant, the consequences of changes induced by well treatments should also be considered. Treatment effects may include extended periods of sloughing from the well as damaged clog components are dislodged and pumped out. In general, treatment plant effects expected should include direct adverse effects on treatment plant performance, input and output effects, and institutional loss of confidence.

a. Direct adverse effects on treatment plant performance. These effects include:

- Excessive organic loading ((biological oxygen demand (BOD), chemical oxygen demand (COD), etc.)) of the plant.
- Acid solution pH shock, which may be particularly disruptive for activated carbon or biological digestion systems (relying on attached microflora). These should be neutralized to within stated plant tolerance.
- Process disruption due to increased BOD, COD, etc., of the development solution and subsequent pumpage from wells re-establishing the biogeochemical status prior to the treatment event.
- Low contaminant concentration due to plume disruption.
- Sediment production and geochemical alteration of constituents so that they are not as well addressed by the treatment system. Clogging slugs of biofilm and solids (sand, silt, clay) developed out of wells may be particularly destructive to membrane and resin bed treatment systems.
- Fouling of piping, sensors, air strippers, granular activated carbon columns, ultraviolet emission lamps, etc.
- Alteration of geochemistry. Rapid flip-flopping of pH can be expected during treatments. Plants adapted to established reductive water may have to transiently adapt to a more

oxidative Eh. Erratic detections or spikes of compounds whose solubility is redox- or pH-sensitive may occur.

- Metal oxide breakthrough from filters into the rest of the treatment train. Acidic waters may flush attached iron and other metal oxides from filter particle surfaces, and breakthrough may occur, resulting in coating of downstream media and membranes.
- Enhanced cost of operation due to lowered efficiencies and frequent cleaning, backwashing, or replacement of media.

b. Input and output effects. The effects include:

- Pumping well and system clogging, which restricts flow so that cleanup of calculated plume volume is slowed or stopped, or contaminated ground water bypasses the installed system while wells are replaced or rehabilitated.
- Altered aquifer hydraulic conductivity so that the plume bypasses the pumping well array, favoring higher-hydraulic conductivity channels less affected by biofouling.
- If injection wells cannot take enough water, the plant has to cut back or shut down.

c. Institutional loss of confidence in pump-and-treat strategies. This effect is already apparent in the literature and discussion groups when “pump and treat” is discussed. Arguably, a contributing factor in poor performance in these systems is performance deterioration due to environmental factors such as biofouling that can be addressed through well system PM (Smith 1995; Alford and Cullimore 1999).